Autonomous control of a shop floor based on bee's foraging behaviour

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Results of the CRC 637:
Autonomous Cooperating Logistic Processes:
A Paradigm Shift and its Limitations

Agenda

1. Motivation and Definition of Autonomous Control

2. Approach to Autonomous Control of Shop Floor by the Transfer of Bee's Foraging Behaviour

3. Modelling and Simulation Details

4. Simulation Results

5. Summary and Outlook

Motivation and Definition of Autonomous Control

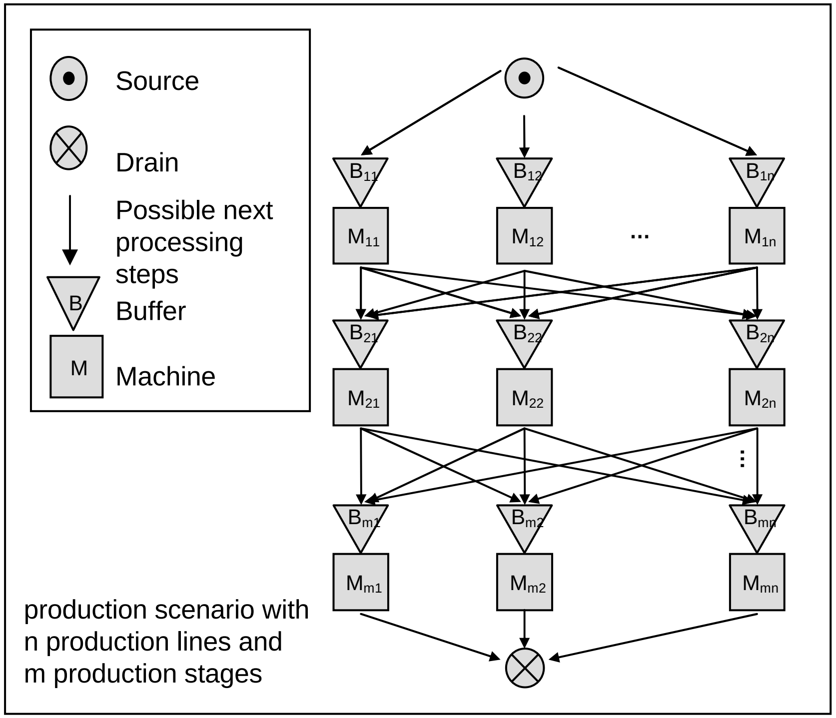
Motivation

- Apparently present production planning and control systems are unable to cope with the increasing complexity and dynamics in the production and logistic environment.

  ➡ This leads to the introduction of autonomous control strategies.

Autonomous Control …

is characterized by a **decentralized coordination** of **intelligent logistic objects** and the **routing** through a logistic system by the intelligent objects themselves in a **dynamically changing environment.**



Required for application:

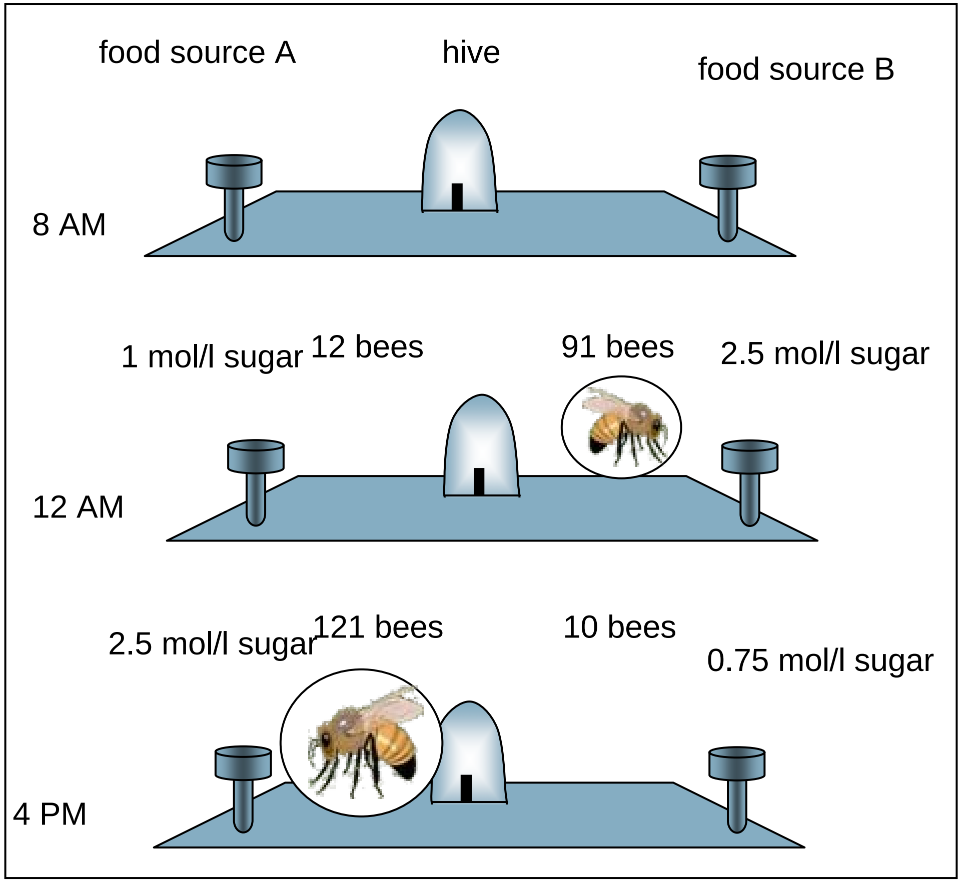
- Local decision rules that allow the autonomous decision making.
- Global objectives are reached through interaction and emergent behaviour.

Existing Autonomous Control Strategies for Shop Floor Control

- Queue length estimator – based on forecasts.
- Pheromone-based approach – based on experience.

→ Adaptive, flexible shop floors;
high degree of logistic objects achievement

Swarm Intelligence in a Beehive



Set-up for the experiment of Seeley (1994):

Two identical food sources with the **same distance** from the hive, the bees exploit the sources **equally.**

8 AM:
sources are modified: identical distance of sources;
source A sugar concentration of 1.0 mol/l; source B 2.5 mol/l.

12 AM:
source A is visited 12 times and source B 91 times;
sources are modified: identical distance: source A 2.5 mol/l; source B 0.75 mol/l.

4 PM:
source A: 121 visits
source B: 10 visits.

Choosing the Best Feeding Place

- Forager bees **travel** to flower patches, **collect** a load of nectar and then **return** to the hive, where the food is **stored** by so called **worker bees**.

- Bees that are aware of a food source can **either advertise** the source by performing a '**waggle dance**', can **continue to forage** at the food source without recruiting nest mates, or they can **abandon** the food source and go back to the pool of unemployed bees.

- If the bee decides to start **dancing she conveys information** about the known food source to the 'onlooking' bees, i.e. its general **direction, distance, and odour**.

- The **probability of recruiting an onlooker** bee for a particular flower patch is **directly proportional to the number of dances performed for that source**. The length of those dances in turn is proportional to source quality.
  ⇨ **Thus more bees will be recruited to better food sources.**

Control Mechanism

- Every time a forager bee turns back to the hive from a flower patch it brings home **information about the food source**.
  It can share the information with temporarily unemployed bees by the **`waggle-dance`**.

- Each homecoming bee **evaluates the food source** by means of the **ratio of energy consumption to the energy conveyed to the hive**.

Equation found by Seeley (1994): $$\text{source quality} = \frac{\text{gain}\,[J] - \text{costs}\,[J]}{\text{costs}\,[J]}$$

- **The better** the individual evaluation of **the source quality the more dance runs** the bee will perform.

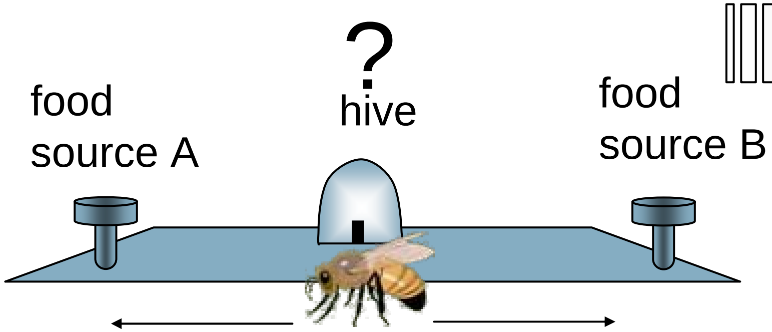
- Experiments have shown that **onlooker bees watch only one single dance** while meeting a dancing bee by chance and leave the dancing bee before the dance is completed.

⇨ This indicates that
  - onlooker bees do not acquire information about the quality of food source.
  - the more runs a dance has, the longer it takes and the more unemployed bees can watch it.
  - the more collecting bees are attracted, the more dances are accomplished.

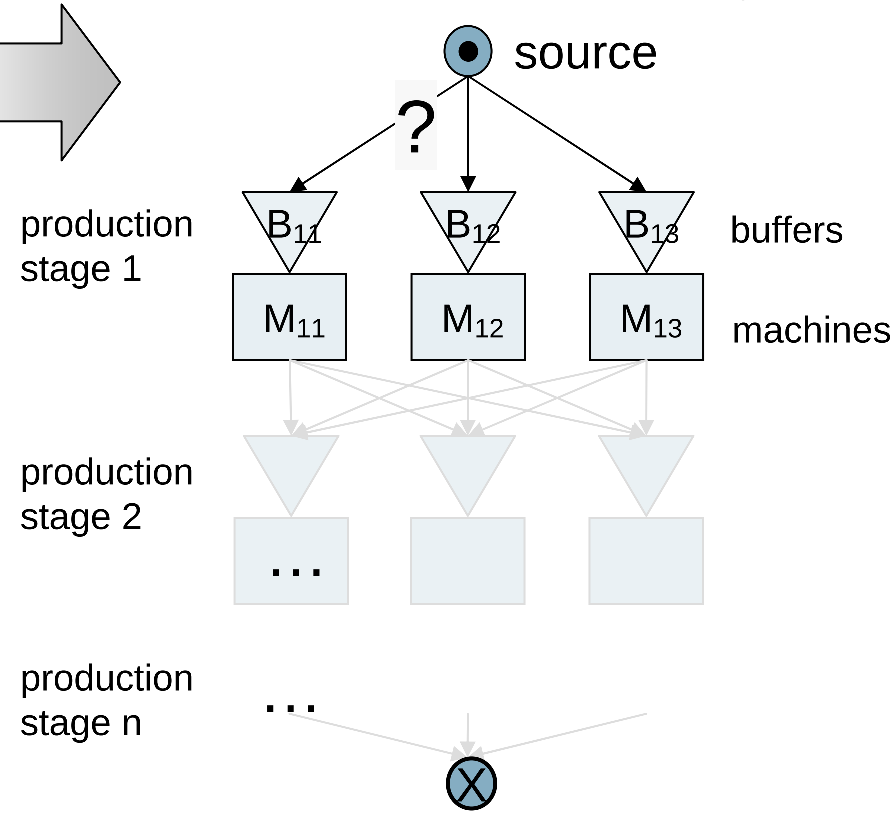
Autonomous Control Strategy for Shop Floor Control

Transfer of bee's foraging behavior of choosing the best feeding place to
the problem of autonomous choice of a part of the following machine to be processed at.

Bee: Which food source to fly to ?



Part: Which machine/buffer to go to ?



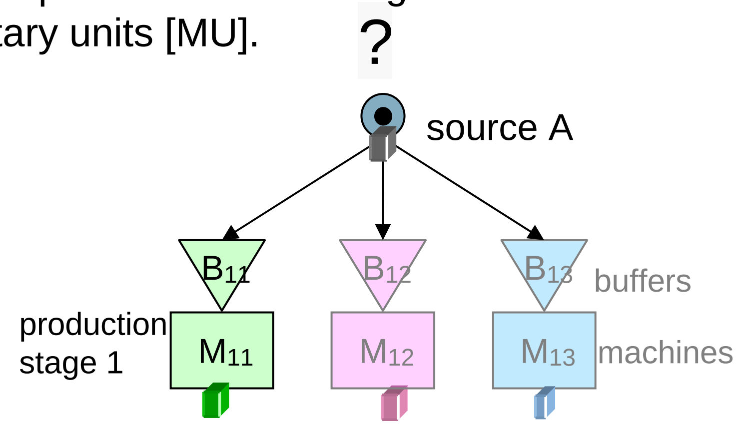
source
drain
Buffer
Machine
possible next processing step

Transfer to Manufacturing System

- A **part leaving the machine after its processing** has to decide about the **duration of a signal** given back to the following parts.
- The **signal strength** is set to the **value of 1** according to the one single bee performing a dance.
- A part's **choice of the next machine is depending on the sum of signals** performed by the preceding parts (**number of signals and the length of the signals**).
- The **evaluation equation** expresses the ratio of the **value added** at one device **reduced by the costs** (caused by time spent for processing, transportation and waiting for each machine and product type) **divided by these costs** in monetary units [MU].

$$machine\_quality = \frac{value\_added[MU] - costs[MU]}{costs[MU]}$$

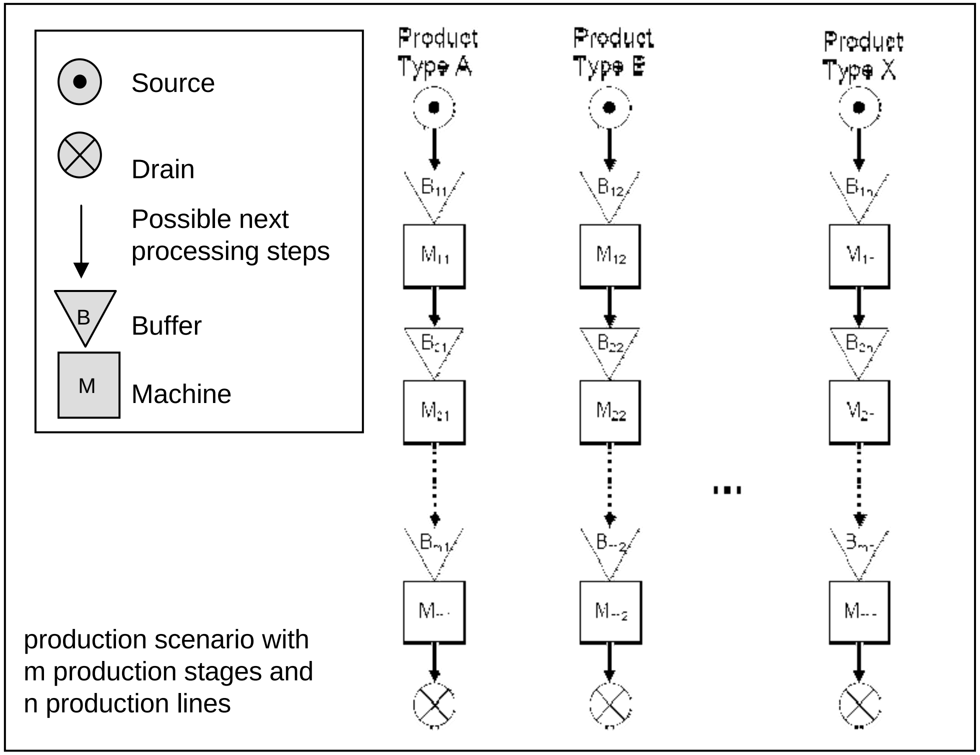
$$\mathrm{MQ}_{mnk}(t) = \frac{\mathrm{VA}_{mk} - \mathrm{TPT}_{mnk}(t) * \mathrm{R}}{\mathrm{TPT}_{mnk}(t) * \mathrm{R}}$$



VA_{mk}	Value Added at stage m to product type k [MU]
TPT_{mnk}	Throughput Time at production stage m, line n for product type k [TU]
R	Cost rate [MU/TU]

Transfer fulfilled in two steps:
1. Shop floor with different processing times
2. Shop floor with different set-up times

Modelling and Simulation Details



production scenario with m production stages and n production lines

Simulation model is reduced to 3x3 in order to handle the complexity:

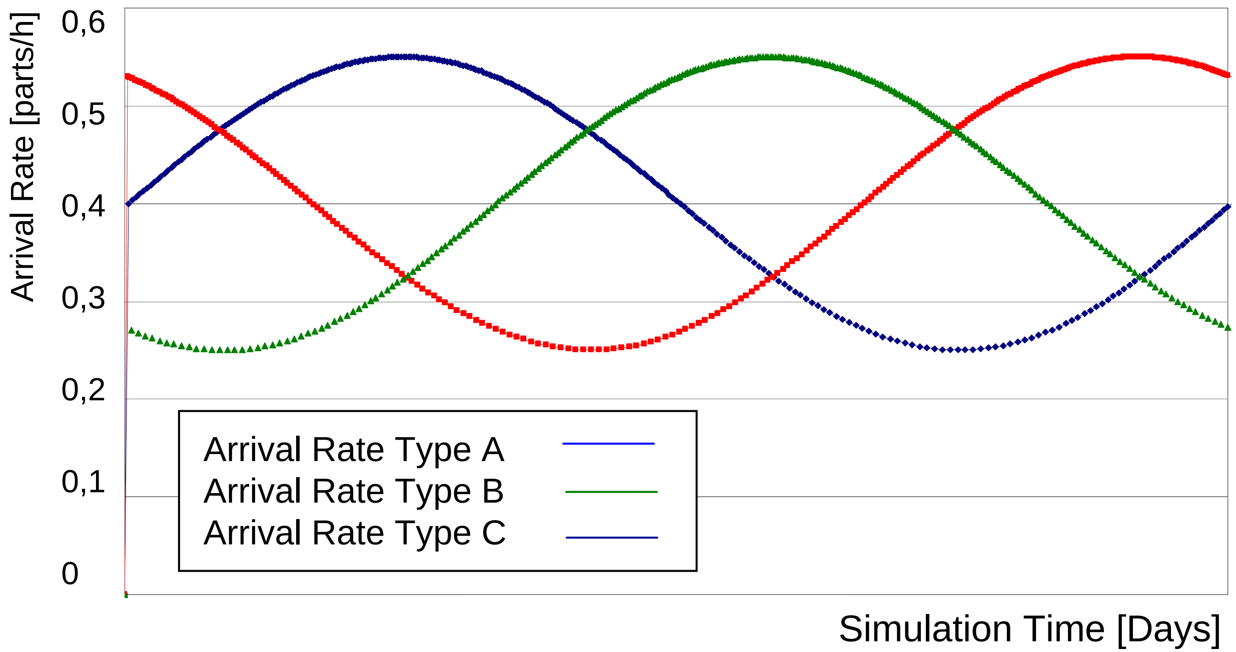
- 3 production lines n
- 3 production stages m
- 3 different product types

processing times T for the product types k [min]	machine M_{m1}	machine M_{m2}	machine M_{m3}
A	120	150	180
B	150	180	120
C	180	120	150

Scenario for varying processing times

- cyclic processing times

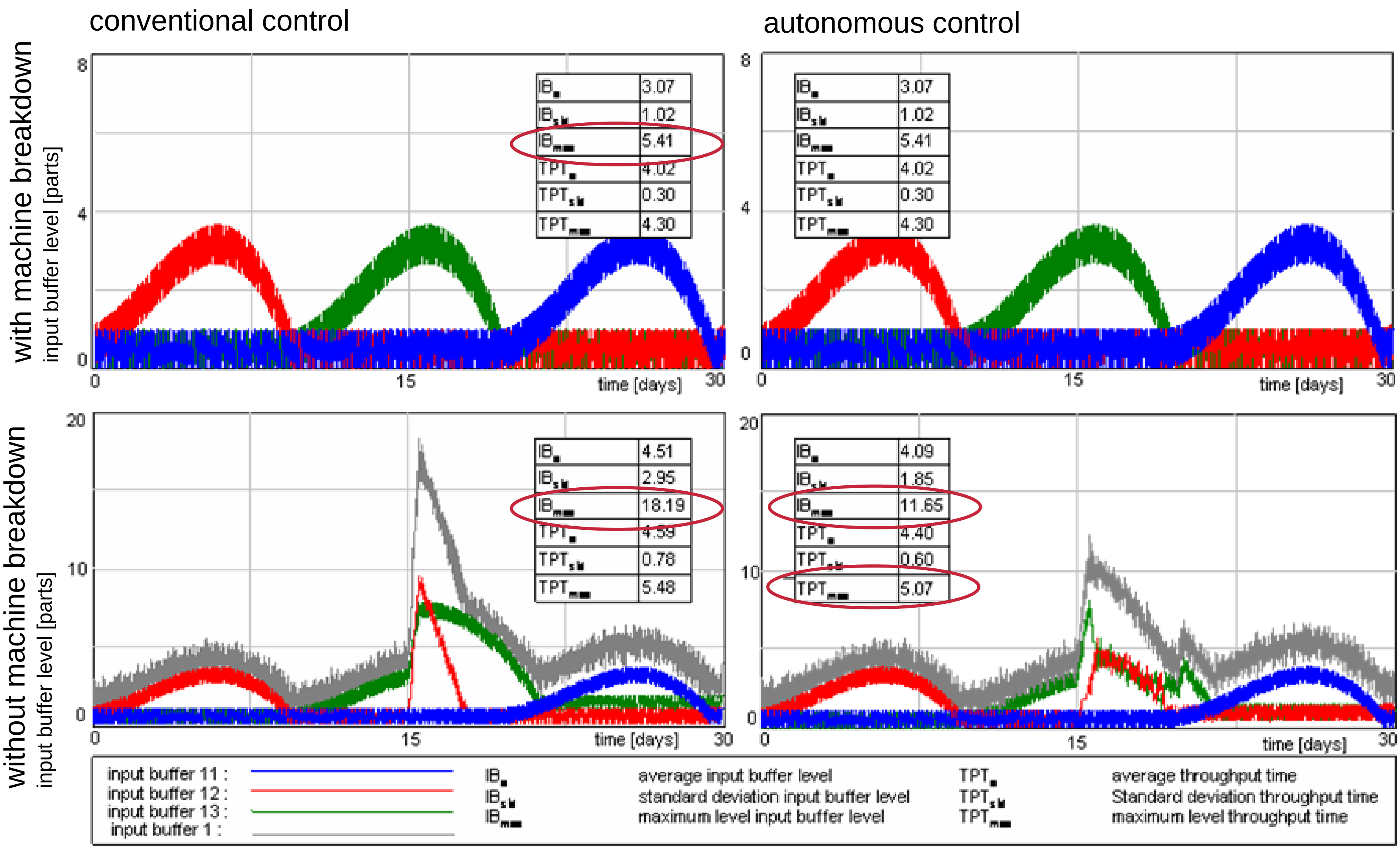
Arrival Rates



- Sine shaped arrival functions (seasonal demand fluctuations)
- Identical, but time shifted functions for the different product types
- Function varies 25% around the mean value
- Mean arrival time per part 144 min
- 30 days simulation time

Scenario for Varying Processing Times Results for Machine Breakdown

Results for 12h machine breakdown of machine M_{12} after 15 days of simulation time:



Scenario with Set-Up Times

- Although there is **nothing comparable to set-up times** in a bee hive it is possible to introduce the meaning of set-up times to the existing model.
- By changing the signal strength (that was set to 1 before) **an additional information** and special advertisement is **given back only to the direct successor part.**

Setup times [min] product type x → y	**machine M_{m1}**	**machine M_{m2}**	**machine M_{m3}**
A→ B	30	10	60
A→ C	60	30	10
B→ A	10	60	30
B→ C	60	30	10
C→ A	10	60	30
C→ B	30	10	60

- Cyclic set-up times
- Processing time for each product type is the same: 120 min

Results for Additional Communication of Set-Up Status

Improved results for the **additional advertisement of the machine's current set-up status** – especially for stronger changing demands.

Amplitude of sine function		**0.3**		**0.5**	
Setup status advertisement (yes/ no)		no	yes	no	yes
INPUT BUFFER [parts]	IB_a	5.88	5.74	6.89	6.44
	IB_{std}	1.78	1.02	1.76	1.50
	IB_{max}	11.87	9.07	13.38	11.45
THROUGH-PUT TIME [h]	TPT_a	6.68	6.18	7.37	6.91
	TPT_{std}	0.46	0.20	0.38	0.25
	TPT_{max}	7.83	6.79	8.50	7.43

IB_a average input buffer level
IB_{std} standard deviation input buffer leve
IB_{max} maximum level input buffer level
TPT_a average throughput time
TPT_{std} Standard deviation throughput time
TPT_{max} maximum level throughput time

Summary and Outlook

Summary

- Autonomous Control is a promising way for coping with increasing complexity and dynamics in the production and logistic environment.
- It is possible to transfer the mechanisms of bee's foraging behavior to the problem of a part's autonomous routing through a shop floor system.
- The bee-like control approach shows the ability to deal with unforeseeable changes in the production environment (e.g. machine breakdowns) as well as with set-up times.
- The key figures of throughput time and buffer levels are improved significantly in comparison with a conventional control approach.

Outlook

- Further development of autonomous control methods.
- Implementation of assembly processes.
- Validation of the simulation by real world data.

Thank you for your attention!